REPORT No. 245

METEOROLOGICAL CONDITIONS ALONG AIRWAYS

By W. R. GREGG
Weather Bureau

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SUMMARY

This report was prepared at the suggestion of, and for publication by, the National Advisory Committee for Aeronautics and is an attempt to show the kind of meteorological information that is needed, and is in part available, for the purpose of determining operating conditions along airways. In general, the same factors affect these operating conditions along *all* airways though in varying degree, depending upon their topographic, geographic, and other characteristics; but in order to bring out as clearly as possible the nature of the data available, a specific example is taken, that of the Chicago-Dallas Airway on which *regular flying begins this year* (1926).

INTRODUCTION

The service that meteorology can render aeronautics may be considered broadly under two general headings: (1) Furnishing in convenient form statistical information based upon many years' records of the principal meteorological elements in different parts of the country; and (2) making quickly available current data and forecasts for specified airways, based upon detailed observations at points along those airways and at other places in contiguous areas. The latter type of service is required for the efficient operation of airways after they are organized and are working on a regular schedule basis. Statistical information, on the other hand, is needed also during the earlier organization stages of airways, when decision must be made regarding the location of landing fields, orientation of airdromes, adoption of flight schedules, etc. At the present time aeronautics in large measure is in the organization stage; and it seems opportune, therefore, to present for selected airways the sort of information that is needed, so far as it is available.

The information required in connection with the development of what may be called the ground organization—i. e., location and orientation of landing fields, airdromes, etc.—can best be obtained by a study of the local records at the places selected. There is often, for example, within small areas wide variation in wind gustiness owing to topographic irregularities, in the occurrence of fog because of differences in elevation, and in visibility since this varies materially on different sides of cities. Other factors to be considered are the average wind velocity, the frequency of various wind directions and velocities, and the occurrence of excessive precipitation, including heavy snow fall. A knowledge of these is necessary in deciding upon the best orientation of airdromes and runways and in providing adequate drainage for landing fields.

The adoption of flight schedules that can be satisfactorily maintained is dependent in part upon two of the factors above listed, visibility and frequency of fog, and in larger part upon several others, of which the most important are the frequency of low clouds, frequency and intensity of thunderstorms and excessive precipitation, and the characteristics of winds at flying levels, particularly the frequency of head and cross winds of sufficient velocity to cut down appreciably the ground speed of the aircraft. Although the data required for this purpose are far from being as complete as they should be, there nevertheless is sufficient information for certain parts of the country to justify the preparation of a preliminary survey or summary which can be revised and improved as added material is accumulated.

THE CHICAGO-DALLAS AIRWAY

The Chicago-Dallas Airway passes through Chicago, Moline, St. Joseph, Kansas City, Wichita, Oklahoma City, Dallas, and Fort Worth. (See fig. 1.) Continuous records of weather conditions have been kept for many years at these places, with the single exception of Moline, and in this case there are available the records at Davenport, which is directly across the Mississippi River. The records at these places are confined to surface conditions, except that they include the kind, amount, and direction of clouds. Visibility has thus far not been observed regularly.

Upper air observations have, however, been made at four places not far from this airway, viz, Royal Center, Ind., Drexel, Nebr., Broken Arrow, Okla., and Groesbeck, Tex. Their locations are shown in Figure 1. At these stations regular observations have been made of wind direction and velocity at different levels, heights of clouds, particularly of the lower forms, and visibility. It is thus possible, by utilizing the data from both surface and upper air stations, to gain a very good idea concerning the conditions which on the average will be experienced in

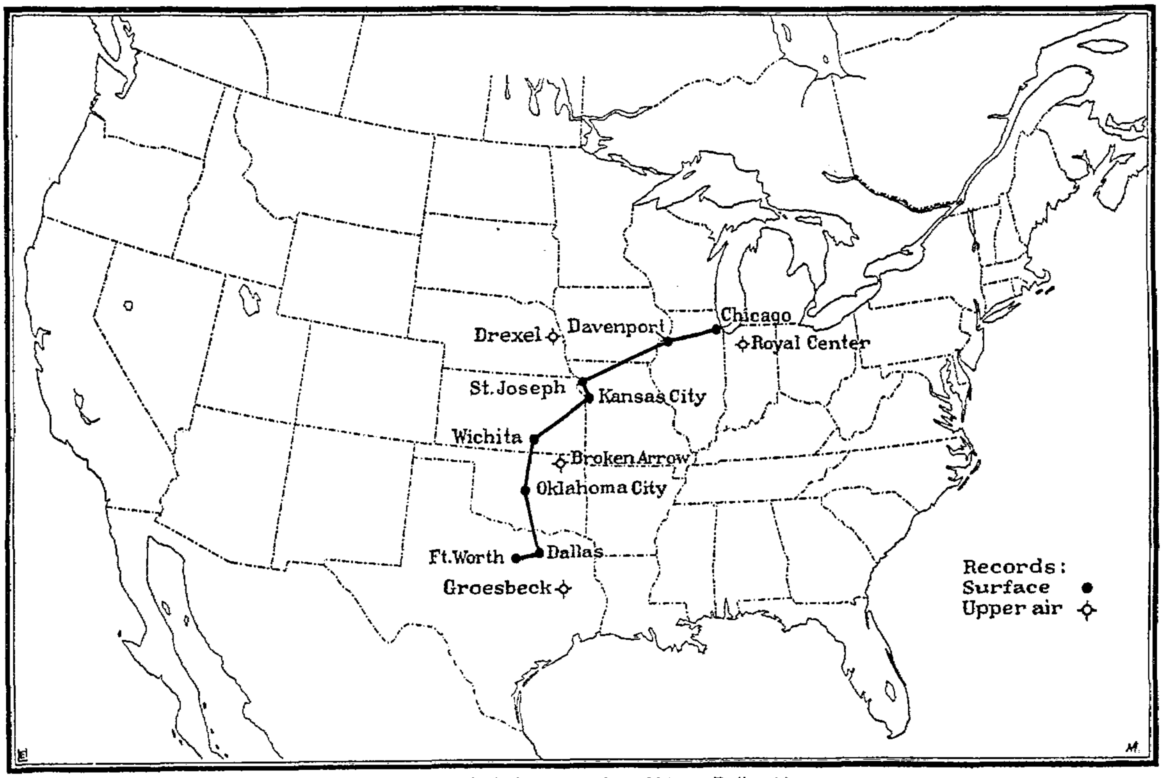

FIG. 1.—Meteorological stations along Chicago-Dallas Airway

flights along the Chicago-Dallas Airway. The meteorological factors or elements of most importance in connection with flight schedules are visibility; frequency of fog and low clouds; frequency and intensity of precipitation; frequency and intensity of thunderstorms; and upper winds, particularly the frequency of winds of different directions and velocities.

VISIBILITY

For several years horizontal visibility has been observed twice daily at the four aerological stations above named, viz, Royal Center, Drexel, Broken Arrow, and Groesbeck. The observations are made by noting the greatest distance to which prominent objects on the earth's surface can be seen. An arbitrary scale of distances is used, as follows: 160, 650, 1,600, 3,300, 6,600, 13,100, 23,000, 39,400, and 98,400 feet.[1] Aeronautics is most concerned with the lower values, but

[1] The international visibility scale is 50, 200, 500, 1,000, 2,000, 4,000, 7,000, 12,000 and 30,000 meters, and observations in the United States are made in accordance with this scale. In the present paper English equivalents are used. This is true also of heights and wind velocities, although both units are employed in the tables. The conversion into English units, though not exact (i. e., to the nearest foot) is sufficiently close for all practical purposes.

in Table I frequencies for the season and year are given for 650, 1,600, 3,300, 13,100, and 23,000 feet, the stations being given in the order of their locations from north to south along the airway. These stations are at a considerable distance from large cities, and the data therefore refer to conditions in the country where naturally most of the flying will be done. Visibilities in and close to cities are on the average considerably less than those given in Table I, owing to smoke, dust, etc.

It is evident that along this airway the frequency of very low visibilities is not a serious factor, those of less than 650 feet, for example, occurring only about 1 or 2 per cent of the time, with little seasonal, daily or regional variation. The higher visibilities, however, are most frequent in summer and least in winter, with spring and autumn agreeing closely with each other and with the annual mean. Moreover, the data show considerably better visibility in the afternoon than in the early morning and in the southern than in the northern sections of the airway.

TABLE I

AVERAGE SEASONAL AND ANNUAL FREQUENCY OF VISIBILITY LESS THAN 650, 1,600, 3,300, 13,100 AND 23,000 FEET AT CERTAIN STATIONS

ROYAL CENTER, IND., 7 A. M

Visibility less than		Spring	Summer	Autumn	Winter	Annual
Meters	*Feet*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
200	650	2	1	2	4	2
500	1,600	7	3	9	9	7
1,000	3,300	11	5	13	17	12
4,000	13,100	42	31	48	59	45
7,000	23,000	79	71	80	90	80

ROYAL CENTER, IND., 2 P. M.

200	650	1	0	1	2	1
500	1,600	4	1	5	7	4
1,000	3,300	6	2	6	11	6
4,000	13,100	20	8	16	33	19
7,000	23,000	46	30	44	63	46

DREXEL, NEBR., 7 A. M.

200	650	4	[1]0	2	6	3
500	1,600	8	6	6	9	7
1,000	3,300	13	10	10	14	12
4,000	13,100	23	16	18	22	20
7,000	23,000	44	39	42	44	42

DREXEL, NEBR., 3 P. M.

200	650	1	0	1	4	1
500	1,600	5	3	5	7	5
1,000	3,300	6	4	6	10	7
4,000	13,100	15	7	12	18	13
7,000	23,000	38	29	36	42	36

BROKEN ARROW, OKLA., 7 A. M.

200	650	1	[1]0	2	2	1
500	1,600	6	3	6	8	6
1,000	3,300	10	5	11	16	11
4,000	13,100	25	14	26	31	24
7,000	23,000	53	43	59	65	55

BROKEN ARROW, OKLA., 3 P. M.

200	650	[1]0	0	[1]0	1	[1]0
500	1,600	4	1	4	7	4
1,000	3,300	5	1	5	10	5
4,000	13,100	12	2	12	18	11
7,000	23,000	34	15	28	43	30

[1] Less than 0.5 per cent.

TABLE I—Continued

AVERAGE SEASONAL AND ANNUAL FREQUENCY OF VISIBILITY LESS THAN 650, 1,600, 3,300, 13,100 AND 23,000 FEET AT CERTAIN STATIONS—Continued

GROESBECK, TEX., 7 A. M.

Visibility less than—		Spring	Summer	Autumn	Winter	Annual
Meters	*Feet*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
200	650	1	0	1	3	1
500	1,600	4	1	4	8	4
1,000	3,300	13	6	12	20	13
4,000	13,100	16	8	15	24	16
7,000	23,000	30	18	30	39	29

GROESBECK, TEX., 2 P. M.

200	650	[1] 0	0	0	1	[1] 0
500	1,600	2	1	3	6	3
1,000	3,300	3	1	3	9	4
4,000	13,100	4	1	5	11	5
7,000	23,000	12	7	10	19	12

[1] Less than 0.5 per cent.

These characteristic differences for visibilities less than 1,600 and 13,100 feet, are shown in greater detail in Figures 2 and 3.

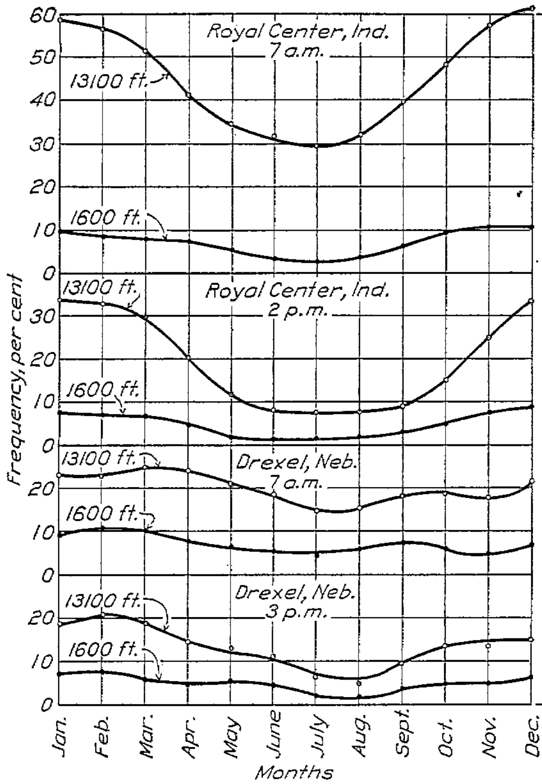

FIG. 2.—Annual variation in frequency of visibilities less than 1,600 and 13,100 feet at Royal Center, Ind., and Drexel, Nebr.

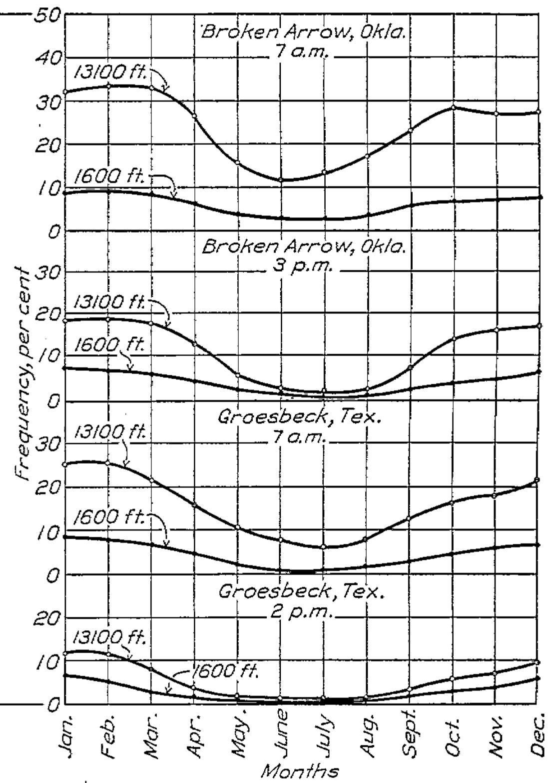

FIG. 3.—Annual variation in frequency of visibilities less than 1,600 and 13,100 feet at Broken Arrow, Okla., and Groesbeck, Tex.

It should be borne in mind that the data here presented are for *horizontal* visibilities only. In some cases, owing to low clouds, the vertical visibility may be very low, while that in a horizontal sense is relatively high. As a rule, however, the latter is low also when this condition prevails. Horizontal visibility is observed in two or more directions, north and south for example, and an average value taken. Observations are made on all days, including those in which rain or snow is falling.

FOG AND LOW CLOUDS

Dense fog is of such infrequent occurrence in the interior portions of the country that it offers no real obstacle to the maintenance of flight schedules. In general there are less than 10 days with dense fog per year. For the most part these fogs are of the radiation type, lasting therefore only during the night or until shortly after sunrise and being in general less than 300 feet deep. They are rarely widespread but occur in river bottoms or other low-lying places. At Chicago fogs are occasionally blown in from the lake or are caused by moist lake winds blowing over the colder surface of the ground. Occasionally also a combination of low clouds, smoke, and high humidity produces a condition closely resembling fog, the so-called "dark days." Such conditions fortunately are confined to the city limits and moreover do not as a rule occur more than four or five times a year, usually in the period December to March.

TABLE II

AVERAGE SEASONAL AND ANNUAL FREQUENCY OF CLOUDS BELOW SELECTED HEIGHTS AT CERTAIN STATIONS

Height		Spring	Summer	Autumn	Winter	Annual
ROYAL CENTER, IND., 7 A. M.						
Meters	*Feet*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
150	500	5	2	6	11	6
300	1,000	11	5	12	18	11
500	1,600	18	8	17	27	17
1,000	3,300	26	12	27	40	26
1,500	4,900	31	16	31	46	31
ROYAL CENTER, IND., 2 P. M.						
150	500	2	[1] 0	2	5	2
300	1,000	5	1	5	11	6
500	1,600	13	2	11	23	12
1,000	3,300	26	8	20	41	24
1,500	4,900	34	18	28	46	32
DREXEL, NEBR., 7 A. M.						
150	500	6	5	5	7	6
300	1,000	11	8	8	11	10
500	1,600	17	11	12	17	14
1,000	3,300	22	15	18	23	20
1,500	4,900	25	18	20	27	23
DREXEL, NEBR., 3 P. M.						
150	500	1	1	2	3	2
300	1,000	3	2	5	7	4
500	1,600	8	4	8	14	8
1,000	3,300	18	10	21	24	18
1,500	4,900	25	17	21	27	22
BROKEN ARROW, OKLA., 7 A. M.						
150	500	6	3	8	11	7
300	1,000	9	4	11	16	10
500	1,600	13	6	15	21	14
1,000	3,300	22	9	19	27	19
1,500	4,900	24	11	21	30	22
BROKEN ARROW, OKLA. 3 P. M.						
150	500	2	1	2	5	2
300	1,000	4	1	5	9	5
500	1,600	8	2	9	15	9
1,000	3,300	16	4	14	25	15
1,500	4,900	22	9	17	26	19
GROESBECK, TEX., 7 A. M.						
150	500	10	7	11	17	11
300	1,000	13	9	14	21	14
500	1,600	23	14	18	28	21
1,000	3,300	32	16	23	38	27
1,500	4,900	35	17	26	41	30

[1] Less than 0.5 per cent.

TABLE II—Continued

AVERAGE SEASONAL AND ANNUAL FREQUENCY OF CLOUDS BELOW SELECTED HEIGHTS AT CERTAIN STATIONS—Continued

GROESBECK, TEX., 2 P. M.

Height		Spring	Summer	Autumn	Winter	Annual
Meters	*Feet*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
150	500	2	[1] 0	2	5	2
300	1,000	3	1	3	8	4
500	1,600	6	2	7	14	7
1,000	3,300	14	5	13	24	14
1,500	4,900	20	8	18	32	19

[1] Less than 0.5 per cent.

The frequencies, seasonal and annual, of clouds of different heights are given in Table II. The heights of most interest in aviation are the three lower ones, 500, 1,000, and 1,600 feet, and the frequencies for two of these, 500 and 1,600, are shown also in Figures 4 and 5. A fairly

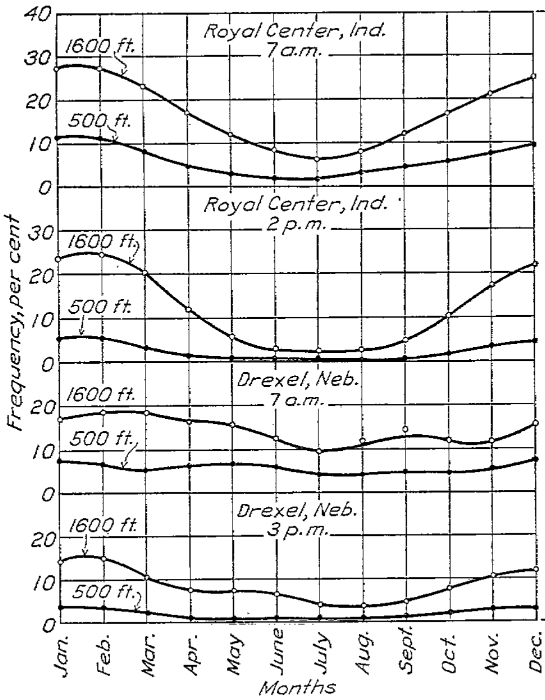

FIG. 4.—Annual variation in frequency of clouds below 500 and 1,600 feet, at Royal Center, Ind., and Drexel, Nebr.

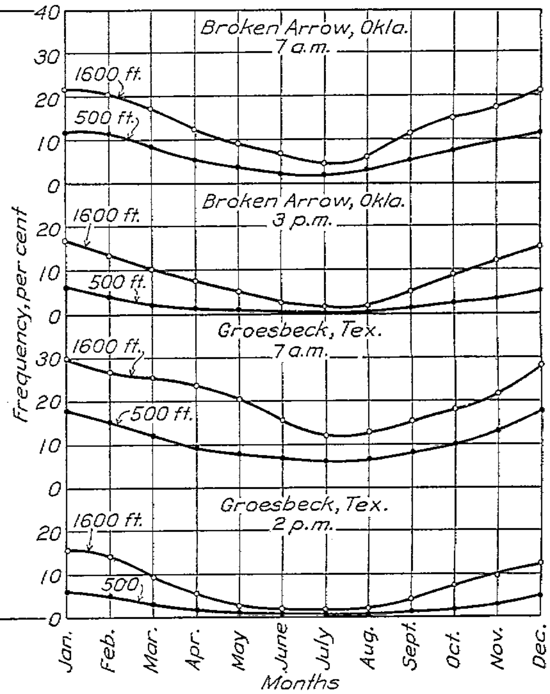

FIG. 5.—Annual variation in frequency of clouds below 500 and 1,600 feet at Broken Arrow, Okla., and Groesbeck, Tex.

pronounced diurnal variation is apparent in all seasons, low clouds being about twice as frequent in early morning as in the afternoon, with an even greater difference than this for the lowest clouds, 500 feet or less. Summer shows the lowest frequency and winter the highest, with the other two seasons approximately equal and differing little from the annual mean. So far as the airway as a whole is concerned, it appears that the central portion has a slightly smaller frequency of low clouds than have the northern and southern sections, the difference being least in summer.

The close relationship between visibility and the occurrence of low clouds is apparent from a comparison of Table I and Figures 2 and 3 with Table II and Figures 4 and 5. To a certain extent the frequency of low clouds, as presented in Table II, may be accepted also as an index of vertical as well as horizontal visibility.

PRECIPITATION

The average annual precipitation along the entire airway, Chicago to Fort Worth, is approximately 35 inches. Of this, some 60 to 70 per cent occurs during the six months, April to September, inclusive. During this period, moreover, there is more rain at night than in the daytime, the heaviest being near sunrise and the least in the early afternoon. For the region as a whole about 55 to 60 per cent occurs between 7 p. m. and 7 a. m., the amount being somewhat less than this in northern Illinois and northeastern Texas and slightly greater along the remainder of the airway.

The number of days with precipitation in measurable amounts, 0.01 inch or more, decreases from about 120 at Chicago to somewhat less than 80 at Dallas and Fort Worth. The seasonal distribution varies somewhat in different sections of the airway. For example, at Chicago the average number per month is about 9 from July to November, inclusive, and 11 during the remainder of the year; at St. Joseph, Mo., 6 in autumn and winter and 10 in spring and summer; and at Oklahoma City, 8 to 10 in spring and 6 in the other months.

Fortunately the days with light to moderate falls, 0.01 to 0.25 inch, form a fairly large percentage of the total number, about 65 per cent at Chicago and 60 at Fort Worth. Of the remainder nearly all have amounts from 0.26 to 1 inch. Falls in excess of 2 inches occur on the average only once or twice a year.

Snowfall varies widely in different sections of this airway. The average annual amount is about 30 to 35 inches at Chicago, 30 at Davenport, 20 at St. Joseph and Kansas City, 5 at Oklahoma City, and 1 to 5 at Dallas and Fort Worth. The snow problem is thus a serious one only in the northern third of the airway, and even here it is less serious than farther east. Really heavy falls are not frequent, 10 to 11 inches in 24 hours being about the limit, with 13 as the record for Chicago. Only rarely, moreover, is the accumulated amount on the ground more than this. January and February are the worst months.

Snow in measurable amounts, 0.1 inch or more, occurs on about 35 days at Chicago, decreasing to 3 or 4 at Dallas and Fort Worth. The number of days with snow cover varies from nearly 60 at Chicago and Davenport to 1 or 2 at Dallas and Fort Worth.

THUNDERSTORMS

The average frequency of thunderstorms at selected places along the airway is given in Table III. May to August are the months of greatest frequency, thunderstorms occurring then on about one day in four. During the four months, November to February inclusive, the number of thunderstorms is so small that they do not constitute a serious factor so far as flight schedules are concerned.

The characteristics of thunderstorms are too well known to need discussion here. In one respect, however, those of the central part of the United States are unique. In practically all other parts of the world they are most frequent when convection is most active, viz, during the afternoon, and least frequent during the night and early morning. In the Central States, on the other hand, particularly in Iowa, Nebraska, Kansas, and northwestern Missouri, more thunderstorms occur at night than in the daytime, the ratio being as high as 2 to 1 in summer at Lincoln, Nebr. Even at Chicago, the number from 6 p. m. to 6 a. m. is almost exactly the same as that during the remaining 12 hours. Night thunderstorms are frequently of considerable severity and accompanied by heavy rainfall. In fact the nocturnal maximum of precipitation in summer, already discussed, is directly related to this distribution of thunderstorm frequency.

TABLE III

AVERAGE NUMBER OF DAYS WITH THUNDERSTORMS ALONG THE CHICAGO-FORT WORTH AIRWAY

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Chicago	(1)	(1)	3	3	5	8	7	7	5	2	1	(1)	41
Davenport	(1)	(1)	2	3	7	8	8	7	6	2	1	(1)	44
St. Joseph	(1)	(1)	3	4	7	9	8	8	7	2	1	(1)	49
Kansas City	1	1	4	5	8	10	10	9	7	3	1	(1)	59
Oklahoma City	1	1	3	5	7	9	6	7	5	3	1	(1)	48
Dallas	2	3	4	8	8	8	5	7	4	3	2	2	56
Fort Worth	2	2	4	7	9	8	6	7	5	3	1	1	55

[1] Considerably less than 1 on the average.

TEMPERATURE

Air temperatures have less influence upon the maintenance of schedules and upon operations generally along airways than have the other meteorological factors discussed in this paper. However, a knowledge of them is of sufficient interest perhaps in connection with the comfort of pilots and passengers to justify a brief statement.

At the surface the average temperature for the year is about 50° F. at Chicago, increasing quite regularly southward to about 65° at Dallas and Fort Worth. In all parts of this airway the coldest month as a rule is January, with a mean of 20° to 25° at Chicago and 45° at Dallas and Fort Worth; and the warmest is July, with 70° to 75° and 80° to 85°, respectively. Extremes of temperature are not uncommon, values above 100° having been observed over this entire region, though most frequently, of course, in the southern portion. Here, however, the hot spells are usually very dry. Temperatures below zero are occasionally observed, the lowest ever recorded being about −30° in northern Illinois and −10° in northeastern Texas. The average number of days in a year with freezing or below ranges from slightly more than 100 in the northern part to about 35 in the southern.

For the year as a whole the temperature decreases with altitude at the rate of about 3° F. per 1,000 feet. There is, however, a rather large variation in this rate with season and with types of weather. When hot weather prevails at the surface, the temperature decrease is as a rule about double its normal value, the result being cool, comfortable conditions at a comparatively low altitude. On the other hand, with excessively low temperatures at the surface there is ordinarily found little change, frequently an increase, with altitude. For example, the lowest temperature ever observed up to 15,000 feet along this airway is −30° F., which is also approximately the surface record. In other words, during cold spells any provision that is made to insure comfort at the surface will also be sufficient for this purpose at flying levels up to 10,000 or 15,000 feet.

WINDS

Observations of upper air winds by means of kites and pilot balloons have been made twice daily at several places not far distant from the Chicago-Dallas Airway. A summary of the data indicates the desirability of considering wind conditions along three sections of the airway separately, viz, Chicago to Davenport, Davenport to St. Joseph, and St. Joseph to Fort Worth. The average velocities at certain heights along these sections are given in Table IV. These values are the means of all observations, irrespective of direction. It will be noted that at altitudes within which most flying is done, viz, 1,600 to 6,600 feet, there is little variation in different parts of the airway, velocities being slightly lower in the southern section than in the other two, a difference that increases somewhat at still greater altitudes.

TABLE IV

AVERAGE WIND VELOCITIES AT SELECTED LEVELS ALONG THE CHICAGO-DALLAS AIRWAY

Station	Surface		250 800		500 1,600		1,000 3,300		2,000 6,600		4,000 meters 13,100 feet	
Chicago to Davenport:	*M.p.s.*	*Ft./sec.*	*M.*	*Ft.*	*M.*	*Ft.*	*M.*	*Ft.*	*M.*	*Ft.*	*M.*	*Ft.*
Spring	4.8	15.7	8.7	28.5	9.9	32.5	10.2	33.5	12.4	40.7	16.7	54.8
Summer	3.5	11.5	6.2	20.3	6.8	22.3	7.0	23.0	8.0	26.2	10.0	32.8
Autumn	3.9	12.8	7.6	24.9	8.6	28.2	9.1	29.9	11.2	36.7	14.8	48.6
Winter	4.6	15.1	8.8	28.9	10.4	34.1	12.1	39.7	15.2	49.9	21.5	70.5
Annual	4.2	13.8	7.9	25.7	9.0	29.3	9.7	31.5	11.8	38.4	15.8	51.7
Davenport to St. Joseph:												
Spring	6.5	21.3	9.9	32.5	10.7	35.1	10.8	35.4	11.4	37.4	15.8	51.8
Summer	5.2	17.1	8.7	28.5	9.3	30.5	9.2	30.2	9.8	32.2	12.8	42.0
Autumn	5.8	19.0	9.8	32.2	10.8	35.4	11.1	36.4	12.2	40.0	17.6	57.7
Winter	6.2	20.3	10.0	32.8	11.7	38.4	13.2	43.3	15.3	50.2	20.6	67.6
Annual	5.9	19.4	9.6	31.5	10.6	34.8	11.1	36.3	12.2	40.0	16.7	54.8
St. Joseph to Fort Worth:												
Spring	5.7	18.7	10.0	32.8	11.3	37.1	10.9	35.8	11.7	38.4	15.7	51.5
Summer	4.2	13.8	7.9	25.9	9.0	29.5	7.8	25.6	6.5	21.3	7.3	24.0
Autumn	4.9	16.1	9.5	31.2	10.9	35.8	10.3	33.8	10.2	33.5	12.3	40.4
Winter	5.5	18.0	9.3	30.5	10.8	35.4	11.9	39.0	13.5	44.3	18.8	61.7
Annual	5.1	16.7	9.2	30.1	10.5	34.5	10.2	33.5	10.5	34.4	13.5	44.3

The sharp increase immediately above the surface is a characteristic feature in all parts of the world and is due to the decreasing effect of turbulence with altitude. This is peculiarly a nocturnal and early morning phenomenon. During the day there is convectional turbulence which extends to 3,000 feet or more and which results in lower velocities at all levels above the surface. In other words, a rather pronounced diurnal variation is found from 300 to approximately 5,000 feet, opposite in phase to that at the surface and of much greater amplitude—about 10 to 13 feet per second at 1,600 feet. The diurnal range is important in regular flight schedules, since it means that on the average in a region where the wind is prevailingly south, for example, flights northward can be made to best advantage at night or in the early morning, and those southward in the mid-afternoon. This is true for the St. Joseph to Fort Worth section of the airway, where southerly winds prevail at flying levels, as will be shown later.

A feature brought out by the values in Table IV is the relatively small increase from 1,600 to 3,300 feet. Although this is nearly always shown in the average of a large number of cases, it is not so decidedly characteristic as is the large increase from the surface to about 1,600 feet. In fact, the wind conditions between 1,600 and 3,300 feet vary markedly from a large increase to a sharp decrease with height. The latter is the more frequent, particularly in the summer half of the year, when even the average shows a decrease. In the southern section of the airway wind velocities during summer show, on the average, little change at all levels up to 20,000 or 25,000 feet.

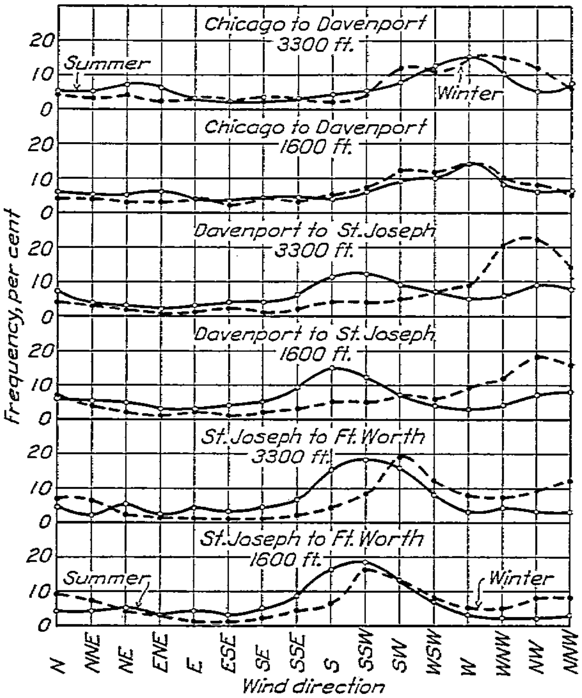

FIG. 6.—Frequency of different wind directions at 1,600 and 3,300 feet along certain sections of the Chicago-Dallas Airway

The average annual frequencies of different wind directions are given in Table V, and the summer and winter values for 1,600 and 3,300 feet only are shown in Figure 6. A marked south component is evident in the lower levels in all parts of the airway. It is most pronounced, however, between St. Joseph and Fort Worth and in the summer half of the year. A conspicuous feature brought out by Table V is the very decided preponderance of winds from west to northwest at the higher levels, particularly in the northern part of the airway.

TABLE V

AVERAGE ANNUAL FREQUENCY OF UPPER WINDS OF DIFFERENT DIRECTIONS ALONG THE CHICAGO-DALLAS AIRWAY

	Altitude					
	Surface	250 meters, 800 feet	500 meters, 1,600 feet	1,000 meters, 3.300 feet	2,000 meters, 6,600 feet	4,000 meters, 13,100 feet
Chicago to Davenport:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
N	4	5	5	5	5	3
NNE	4	5	4	4	3	3
NE	5	4	4	5	3	1
ENE	5	4	4	3	1	1
E	4	4	4	3	2	1
ESE	4	3	3	2	1	1
SE	5	4	3	2	1	1
SSE	6	5	4	4	3	1

TABLE V—Continued

AVERAGE ANNUAL FREQUENCY OF UPPER WINDS OF DIFFERENT DIRECTIONS ALONG THE CHICAGO-DALLAS AIRWAY—Continued

	Altitude					
	Surface	250 meters, 800 feet	500 meters, 1,600 feet	1,000 meters, 3,300 feet	2,000 meters, 6,600 feet	4,000 meters, 13,100 feet
Chicago to Davenport—Continued.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
S	8	7	6	4	3	4
SSW	9	9	9	7	5	3
SW	10	11	11	11	9	7
WSW	9	10	11	12	13	8
W	8	10	12	14	14	17
WNW	6	8	8	10	17	20
NW	5	5	6	8	12	21
NNW	4	6	6	6	8	8
Calm	4	[1] 0	[1] 0	0	[1] 0	[1] 0
Davenport to St. Joseph:						
N	7	7	7	6	4	4
NNE	6	5	4	3	2	2
NE	4	4	4	3	1	1
ENE	3	3	2	1	1	1
E	3	3	3	2	1	1
ESE	4	3	3	3	1	1
SE	6	5	4	3	2	1
SSE	8	7	6	4	2	1
S	10	10	10	8	3	1
SSW	8	10	10	9	7	2
SW	6	7	7	8	9	6
WSW	5	5	5	7	9	8
W	4	4	6	8	12	19
WNW	7	6	7	11	19	22
NW	9	11	11	14	18	21
NNW	9	10	11	10	9	9
Calm	1	[1] 0	[1] 0	0	[1] 0	[1] 0
St. Joseph to Fort Worth:						
N	8	7	6	6	4	5
NNE	7	7	6	4	3	3
NE	4	5	5	4	2	3
ENE	3	3	3	2	2	2
E	2	2	2	3	2	2
ESE	4	2	2	2	2	2
SE	7	4	4	3	2	2
SSE	13	9	6	4	4	2
S	15	17	14	10	6	3
SSW	11	16	18	16	10	5
SW	6	9	11	16	14	7
WSW	3	4	6	9	13	11
W	2	3	4	5	9	15
WNW	3	2	3	4	9	16
NW	4	5	4	5	10	13
NNW	6	5	6	7	8	9
Calm	2	[1] 0	[1] 0	[1] 0	[1] 0	0

[1] Less than 0.5 per cent.

Table 6 gives the frequency of different velocities for summer, winter, and the year. The annual values are means of those in all four seasons and represent quite closely the spring and autumn conditions; the latter are therefore not included in this table.

As would naturally be expected, a very marked seasonal variation is shown, particularly in the higher levels. At 6,600 feet, for example, velocities of 65 ft./sec. and above occur in winter from 10 to 15 per cent of the time, as against 1 to 4 in summer. At 1,600 and 3,300 feet, where most flying is done, strong winds occur somewhat more frequently in both seasons in the section between Davenport and St. Joseph than in the other parts of the airway. In summer, however, they are not a serious factor in any section.

The frequency of low wind velocities does not vary greatly with direction. High velocities, on the other hand, seldom occur with easterly directions, as is well shown in Figures 7 and 8, which give the annual frequencies, at 1,600 and 3,300 feet, respectively, of velocities of 22 and 33 M. P. H. and over along the three sections of the airway. These indicate that from St. Joseph to Fort Worth south component winds at moderate altitudes are not only more frequent but also have higher velocities than do north component winds. Thus, at 3,300 feet, S. to WSW. winds of 22 M. P. H. or more occur 26 per cent of the time or on about one day in four

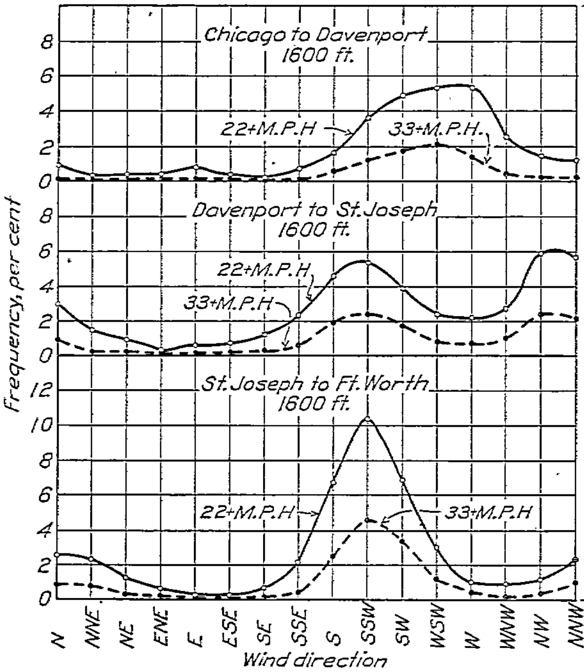

FIG. 7.—Average annual frequency of winds of 22 and 33 M. P. H. and over at 1,600 feet, classified by direction

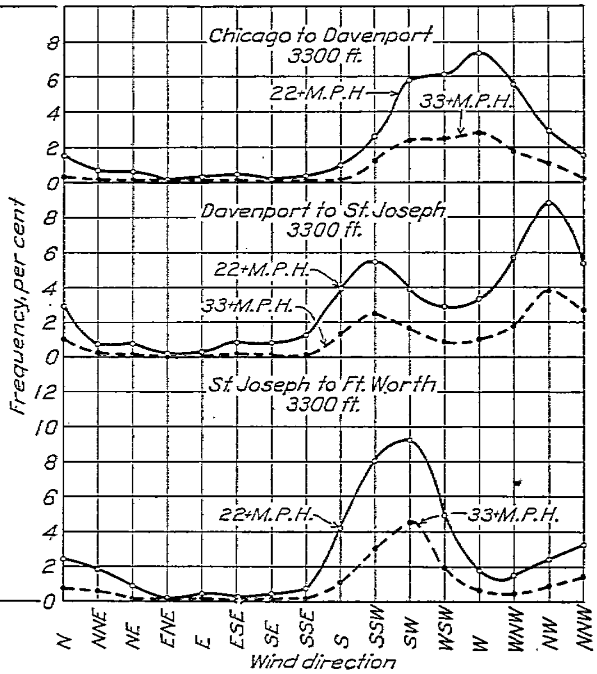

FIG. 8.—Average annual frequency of winds of 22 and 33 M. P. H. and over at 3,300 feet, classified by direction

throughout the year. Curves for the seasons, not reproduced here, show decidedly higher frequencies in winter than in summer, especially with west component winds.

TABLE VI

AVERAGE SUMMER, WINTER, AND ANNUAL FREQUENCY OF UPPER WINDS OF DIFFERENT VELOCITIES ALONG THE CHICAGO-DALLAS AIRWAY

CHICAGO TO DAVENPORT

Velocity		Altitude					
		Surface	250 meters, 800 feet	500 meters, 1,600 feet	1,000 meters, 3,300 feet	2,000 meters, 6,600 feet	4,000 meters, 13,100 feet
M. p. s.	*Ft./sec.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
		Summer					
0–9	0–31	99	92	84	81	73	64
10–19	32–63	1	8	16	19	26	34
20–29	64–96	0	0	[1] 0	0	1	2
30+	97+	0	0	0	0	0	0
		Winter					
0–9	0–31	95	75	61	43	31	25
10–19	32–63	5	25	26	50	55	50
20–29	64–96	0	[1] 0	3	7	13	19
30+	97+	0	0	[1] 0	[1] 0	1	6
		Annual					
0–9	0–31	95	78	68	61	52	44
10–19	32–63	5	22	30	35	41	43
20–29	64–96	0	[1] 0	2	4	7	11
30+	97+	0	0	[1] 0	[1] 0	[1] 0	2

TABLE VI—Continued

AVERAGE SUMMER, WINTER, AND ANNUAL FREQUENCY OF UPPER WINDS OF DIFFERENT VELOCITIES ALONG THE CHICAGO-DALLAS AIRWAY—Continued

DAVENPORT TO ST. JOSEPH

Velocity		Altitude					
		Surface	250 meters, 800 feet	500 meters, 1,600 feet	1,000 meters, 3,300 feet	2,000 meters, 6,600 feet	4,000 meters, 13,100 feet
M. p. s.	*Ft./sec.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
		Summer					
0–9	0–31	89	72	65	66	67	51
10–19	32–63	11	28	33	31	29	43
20–29	64–96	0	[1]0	2	3	4	6
30+	97+	0	0	0	0	0	0
		Winter					
0–9	0–31	84	63	49	38	27	15
10–19	32–63	16	36	45	52	58	57
20–29	64–96	0	1	6	9	14	22
30+	97+	0	[1]0	[1]0	1	1	6
		Annual					
0–9	0–31	85	66	57	54	47	37
10–19	32–63	15	33	39	41	46	45
20–29	64–96	0	1	4	5	6	15
30+	97+	0	[1]0	[1]0	[1]0	1	3

ST. JOSEPH TO FORT WORTH

		Summer					
0–9	0–31	98	93	68	76	86	83
10–19	32–63	2	7	30	23	13	17
20–29	64–96	0	0	2	1	1	[1]0
30+	97+	0	0	0	[1]0	[1]0	0
		Winter					
0–9	0–31	88	69	57	44	35	24
10–19	32–63	12	30	37	50	54	47
20–29	64–96	0	1	6	6	11	25
30+	97+	0	0	0	0	[1]0	4
		Annual					
0–9	0–31	90	71	57	57	57	50
10–19	32–63	10	28	38	40	38	37
20–29	64–96	[1]0	1	5	3	5	12
30+	97+	0	0	[1]0	[1]0	[1]0	1

[1] Less than 0.5 per cent.

Resultant winds,[1] seasonal and annual, are given in Table VII. Features of chief interest are: The large seasonal variation in the upper levels; west component at all levels above the surface; and south component in the lower levels and north component in the upper, the height of change being greater in the southern than in the northern part of the airway.

Resultant winds have an important application in aeronautics. Earlier studies have shown that on the average, air-mail airplanes fly 21 ft./sec. faster from Chicago to New York than in the reverse direction. This value is almost exactly double the resultant wind, 11.2 ft./sec. along this route. In other words, the eastbound airplanes on the average have a tail wind of 11.2 ft./sec. and those westbound a head wind of the same strength. Thus, a knowledge of resultant winds makes possible a determination of flight schedules in each direction, providing the cruising speed of the aircraft is known. Assume this in the present case to be 147 ft./sec (100 M. P. H.), and assume also that flying is done at a height of 1,600 feet. The resultant speed of the aircraft can be found from the equation

$$S_r = S_a \cos \beta \pm S_w \cos \alpha \qquad (1)$$

in which
S_r = resultant speed;
S_a = cruising speed of the aircraft;
S_w = resultant wind;
β = the angle between the heading of the aircraft and the course;
α = the angle between the resultant wind and the course.

[1] Resultant wind is the geometric or vector sum of the individual observations. It is most easily obtained by resolving the observations into their N and W (or S and E) components and adding these algebraically.

β, the angle that the aircraft must make with the course in order to stay on that course is computed from the equation

$$\sin \beta = \frac{S_w}{S_a} \sin \alpha \tag{2}$$

TABLE VII

RESULTANT WIND VELOCITIES ALONG THE CHICAGO-DALLAS AIRWAY

	Surface			Altitude											
				500 meters, 1,600 feet			1,000 meters, 3,300 feet			2,000 meters, 6,600 feet			4,000 meters, 13,100 feet		
	Dir.	Vel.		Dir.	Vel.		Dir.	Vel.		Dir.	Vel.		Dir.	Vel.	
		M./sec.	*Ft./sec.*		*M./sec.*	*Ft./sec.*		*M./sec.*	*Ft./sec.*		*M./sec.*	*Ft./sec.*		*M./sec.*	*Ft./sec.*
Chicago to Davenport:															
Spring	S. 57 W.	1.2	3.9	S. 62 W.	3.3	10.8	S. 76 W.	3.8	12.5	N. 82 W.	5.5	18.0	N. 65 W.	8.5	27.9
Summer	S. 74 W.	.8	2.6	S. 88 W.	2.2	7.2	N. 85 W.	2.7	8.9	N. 73 W.	3.9	12.8	N. 62 W.	5.6	18.4
Autumn	S. 48 W.	1.5	4.9	S. 67 W.	3.4	11.2	S. 81 W.	4.6	15.1	W.	6.5	21.3	N. 82 W.	9.2	30.2
Winter	S. 55 W.	1.5	4.9	S. 73 W.	4.3	14.1	N. 87 W.	7.6	24.9	N. 78 W.	9.8	32.2	N. 72 W.	12.8	42.0
Annual	S. 56 W.	1.2	3.9	S. 71 W.	3.2	21.5	S. 87 W.	4.6	15.1	N 81 W.	6.4	21.0	N. 71 W.	8.9	29.2
Davenport to St. Joseph:															
Spring	S. 85 W.	.3	1.0	S. 63 W.	1.3	4.3	S. 85 W.	2.5	8.2	N. 86 W.	5.3	17.4	N. 73 W.	10.1	33.1
Summer	S. 5 E.	.9	3.0	S. 30 W.	2.1	6.9	S. 61 W.	2.7	8.9	N. 75 W.	4.3	14.1	N. 57 W.	6.9	22.6
Autumn	S. 80 W.	1.3	4.3	S. 76 W.	3.0	9.8	S. 87 W.	4.4	14.4	N. 80 W.	7.3	24.0	N. 73 W.	11.5	37.7
Winter	N.62 W.	2.5	8.2	N. 62 W.	5.9	19.4	N. 62 W.	7.4	24.3	N. 66 W.	11.1	36.4	N. 62 W.	13.5	44.3
Annual	N. 89 W.	.9	3.0	S. 88 W.	2.6	8.5	N. 84 W.	4.0	13.1	N. 75 W.	6.9	22.6	N. 66 W.	10.2	33.5
St. Joseph to Fort Worth:															
Spring	S.	1.8	5.9	S. 22 W.	3.9	12.8	S. 44 W.	4.4	14.4	S. 76 W.	5.8	19.0	N .77 W.	8.9	29.2
Summer	S. 13 E.	2.0	6.6	S. 21 W.	4.3	14.1	S. 29 W.	3.9	12.8	S. 45 W.	2.6	8.5	N. 49 W.	1.9	6.2
Autumn	S. 8 E.	1.2	3.9	S. 27 W.	3.4	11.2	S. 49 W.	3.5	11.5	S. 87 W.	4.0	13.1	N. 79 W.	6.5	21.3
Winter	S. 74 W.	1.0	3.3	S. 77 W.	3.1	10.2	S. 86 W.	5.2	17.1	N.80 W.	8.0	26.2	N. 73 W.	12.0	39.4
Annual	S. 4 W.	1.3	4.3	S. 33 W.	3.6	11.8	S. 54 W.	3.9	12.8	S. 84 W.	4.8	15.7	N. 74 W.	7.2	23.6

The values of α for the three sections of the airway are, approximately,

Chicago to Davenport, 5°;
Davenport to St. Joseph, 47°;
St. Joseph to Fort Worth, 34°.

Substituting in (2), we find the following values of β:

Chicago to Davenport, 0°;
Davenport to St. Joseph, 2°;
St. Joseph to Fort Worth, 3°.

Then, from (1) we get, for S_r,

Chicago to Davenport, 100.0±7.2 M. P. H.;
Davenport to St. Joseph, 99.9±4.0 M. P. H.;
St. Joseph to Fort Worth, 99.9±6.7 M. P. H.

These figures mean that on the average throughout the year, assuming cruising speed of 100 M. P. H. and flight at an altitude of 1,600 feet, the actual ground speed northward would be faster than that southward by the following amounts:

Chicago to Davenport, 21 ft./sec., or 14 M. P. H.
Davenport to St. Joseph, 12 ft./sec., or 8 M. P. H.
St. Joseph to Fort Worth, 19 ft./sec., or 13 M. P. H.

From equations (1) and (2) resultant speeds can be computed for other levels and also for the different seasons. It is evident, from Table VII, that at 13,100 feet neither direction would have much advantage over the other, since the resultant wind is more or less at right angles to the airway. It would therefore somewhat decrease the ground speed in both directions.

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